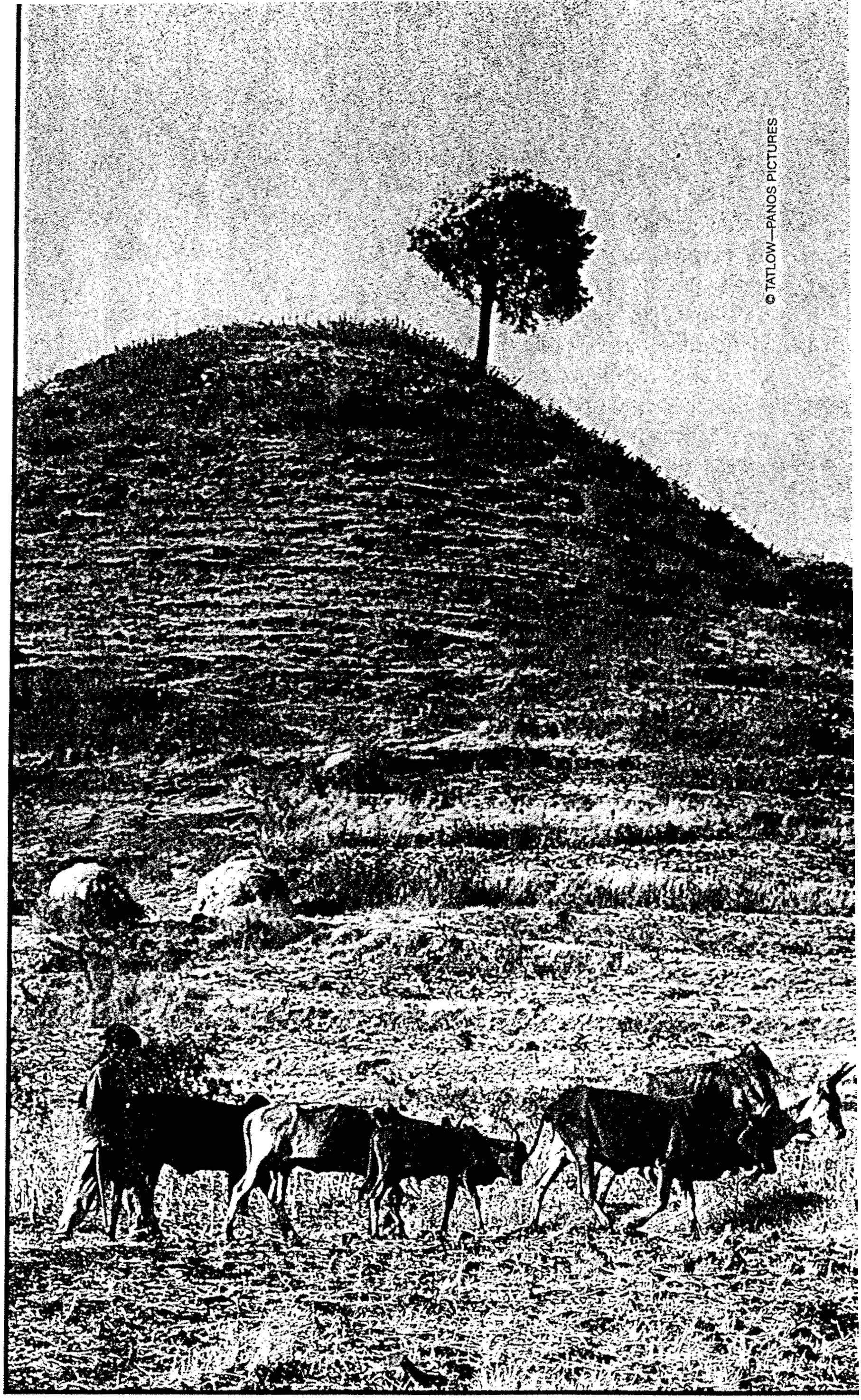
In this age of specialization, men who thoroughly know one field are often incompetent to discuss another.

—Richard P. Feynman, 1965 Nobel laureate

More food will be required in the next 20 years to nourish more people—at least 7.7 billion are expected by 2020. About 800 million of these people will not have enough to eat, not because world food production is inadequate, but because they lack sufficient resources to produce or purchase the food they require. This greater need for food will aggravate agricultural and urbanization pressures in the developing world, where environmental conditions are expected to worsen before getting better.[1]

Further complicating this situation are predictions about what has been called the "next food revolution" in animal agriculture.[2] Owing to more people, urbanization, and growth in per-capita



Environmental Impacts of Livestock in the Developing World

by Charles F. Nicholson, Robert W. Blake, Robin S. Reid, and John Schelhas

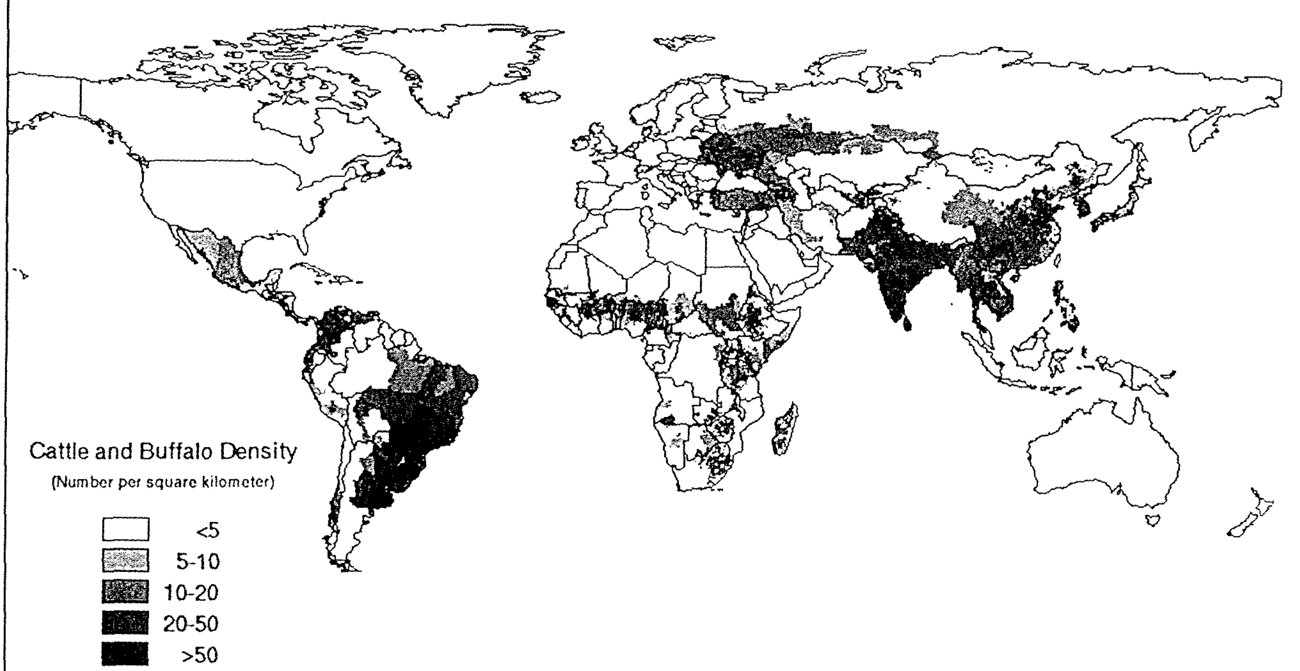
incomes, the nature of world food demand is predicted to change markedly in the next two decades. By 2020, developing country consumers will eat about 87 percent more meat and 75 percent more milk than they do today. The population of developing countries, which comprises three-fourths of the world's total, will consume more than 60 percent of global meat and milk production 20 years from now. This represents a much larger share than the 40 percent of meat and 47 percent of milk developing countries consumed in the early 1990s. In contrast, consumption in developed countries is likely to grow only about as fast as the population. Rapid expected growth in per-capita consumption of food from animals—especially meat and milk—is predicted to make livestock production the largest share of the value of global agricultural output by 2020.

These food demand predictions are potentially double-edged. Rapid growth of an increasingly market-oriented livestock sector portends heightened risks to the environment (e.g., from forest and wetland losses and degradation of soils, water, and vegetation). On the other hand, this increase in demand signifies a critical opportunity for alleviating poverty and spurring economic growth from participation by thousands of small-scale farmers. The alleviation of poverty, which is inextricably tied to economic growth, is also a precondition for avoiding the overexploitation of natural resources. Consequently, it is important to explore the balance between animal agriculture and environmental outcomes—and corresponding human welfare outcomes—in the developing world.

The Complex Role of Livestock in Developing Countries

The world's livestock are found primarily in the agricultural systems of developing countries (see Figure 1 on this page and Table 1 on page 10). The common perception that most livestock are reared intensively in specialized, industrial systems, a phenomenon of the past 50 years in developed countries, does not apply to the developing world. Instead, small, family-run farms that raise both crops and livestock own two-thirds of the world's "walking crops"—livestock. These smallholders raise nine-tenths of the livestock found in developing countries and must carefully manage nutrient stocks and flows that make crop-livestock systems sustainable. Animals in these systems consume little feed edible by humans, obtaining most nutrients from grasslands, scavenged waste, crop residues, and byproducts (see the box on page 11). Through animals, these nutrients are converted into foods of high value, with high concentrations of energy, protein, and micronutrients (vitamins and minerals). Under these circumstances—which differ greatly from those in the developed

Figure 1. Number of cattle and buffalo per square kilometer in the developing world



SOURCES: Central and South America: International Livestock Research Institute (ILRI) and Centro Internacional de Agricultura Tropical; Africa: ILRI; and Asia: Environmental Research Group, Oxford University, and UN Food and Agriculture Organization. Prepared by R. Kruska, GIS Unit, ILRI.

world—smallholders in developing countries produce more than half of global milk and meat supplies. Sales of animals, milk, hides, skins, and manure (for fertilizer or fuel) often constitute a substantial portion of the household's income and are of growing importance as export products. In some areas, livestock constitute the principal savings mechanism for rural households, helping families to contend with inflation, crop failure, and other family needs.

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Forest land in Africa turned to desert by deforestation with subsequent overgrazing. Extensive grazing can cause loss of vegetative land cover, soil compaction, and desertification.

The nonfood uses of livestock remain crucial to rural economies and social and cultural relations in the developing world, although these uses will decline relative to the food function in coming years. The use of animals to plow and cultivate fields and to recycle nutrients from manure—the main fertilizer in developing countries—affects crop production, thus raising incomes and food availability. About one-half of the world's crop production depends on land preparation, such as plowing, made possible by animal traction. Transportation provided by animals increases the access of smallholder farmers to markets in which their produce can be sold. In addition, animals are widely used as dowry, to cement relationships, and to celebrate rites of passage.[3]

Diversity of Livestock Production Systems

About one-third of the dietary protein and one-sixth of the food energy consumed by humans comes from systems involving livestock. The livestock species, number of animals per land area, and use of purchased inputs (feed and fertilizer) are highly variable. Grazing systems, typically with several ruminant species (e.g., cattle, sheep, and goats), rely on native grassland or rangeland without integration of crops or external inputs. Crop-livestock systems, which often involve multiple species of ruminant and monogastric animals (e.g., poultry and pigs), integrate these land-use activities and recycle nutrients. Outputs from one activity are inputs to another: Manure is used as fertilizer, and crop residues are used as feed. Intensive livestock production systems frequently involve a single animal species and use more external inputs than other systems. Intensive systems, such as cattle feedlots, specialized dairy, poultry, and swine farms, are often less connected to feed production, and recycling of nutrients may be limited. More human food is produced from less total feed, land, and animals by intensive systems; however, the higher concentrations of animals can create problems in managing nutrient flows.

In response to expanding urban markets in developing countries, the productivity of the intensive livestock systems is growing twice as fast as mixed crop-livestock systems and six times faster than grazing systems. Production and consumption of livestock products are shifting away from ruminants and toward monogastric animals. Two-thirds of the meat consumed in developing countries today is pork and poultry. This market shift implies greater demand for grain to feed monogastric animals in intensive systems and more excreta that can pollute water supplies.

Health Benefits from Animal Foods

In the developed world, concern about the negative health effects of dietary overconsumption has slowed the growth in demand for animal foods. In marked contrast, demand for animal products in the developing world—where average per-capita consumption is only a fraction of that in developed countries—has increased dramatically. The annual growth rate of total consumption of meat from 1982 to 1994 was 5.4 percent in developing countries but only 1.0 percent in the developed world. Milk consumption grew 3.1 percent per year in the developing world compared to 0.5 percent in developed countries. The percentage of calories provided by animal products increased from 9 to 11 percent in the developing world during this period but decreased from 28 to 27 percent in the developed world. The importance of animal sources of protein in the developing world grew from 21 to 26 percent, whereas this percentage declined from

57 to 56 percent in developed countries. Increasing consumption of meat, milk, and eggs when intake of these foods is low can be nutritionally beneficial, especially for women, infants, and children. In addition to increasing intake of essential amino acids, consuming foods of animal origin alleviates micronutrient deficiencies and improves human nutritional status. Increased animal product consumption has improved the health of pregnant and lactating women, growth and neurobehavioral development of young children, and cognitive development in children. Additional health benefits from other micronutrients have recently been found in the milk and meat of ruminants. Some forms of linoleic acid in these foods inhibit carcinogenesis in experimental animals,[4] improve vitamin A–status, and enhance immune response. In summary, evidence of inadequate dietary quality in the developing world is "revealed by measuring the [low] frequency of consumption of animal products or other nutrient-rich foods."[5]

Livestock and the Need for Intensification

There is broad agreement that agricultural production must become more intensive (produce more per unit of land or per animal) to meet the growing food demands in the developing world. Closer integration of livestock and crop production remains the principal means for intensification of agricultural systems in many regions, particularly the semiarid and subhumid savanna areas of Africa, northeastern Brazil, and much of South Asia. Agropastoral systems (combining crops and livestock) or agrosilvopastoral systems (combining tree species, crops, and livestock) can also improve productivity per unit of land in the humid tropics.[6] Douglas Southgate, professor in the Department of Agricultural Economics at Ohio State University, argues that many of the conservation alternatives to agriculture only work on small scales and in narrow niches, and that more attention should be paid to making existing agricultural lands more productive.[7] Such intensification, through economically viable technological improvement, can be expected to significantly diminish human encroachment on natural habitats. Because cattle pasture occupies a large amount of land in the tropics, and, as has been discussed previously, is an important part of farming systems, possibilities for intensifying pastures should be explored.

Table 1. Livestock numbers in the developed and developing world, 1999

Livestock species	Number of animals (in millions) Developed countries	Developing countries	Total
Cattle	331.4	1,006.8	1,338.2
Buffaloes	0.5	158.1	158.6
Goats	29.2	680.7	709.9
Sheep	390.8	677.9	1,068.7
Camels	0.3	18.9	19.2
Chickens	4,182.5	9,956.8	14,139.3
Pigs	297.5	615.2	912.7

SOURCE: UN Food and Agriculture Organization.

In addition, available evidence suggests that in many regions low-income and landless people earn a greater proportion of their income from the sale of livestock products than do the more affluent in the same rural communities. (The main exception to this finding is the large-scale ranches of Latin America.) Even nonowners of livestock may benefit from growing demand: Evidence from coastal Kenya suggests that the use of more intensive dairy production generated employment for forage production, milking, and milk marketing. Livestock production provides low-income rural people with one of the few market-based opportunities for income and employment available to those with limited land, training, or capital.

Environmental Impacts of Livestock Production

Although livestock provide substantial benefits to people in developing countries, they also contribute to environmental degradation. Livestock production and marketing have been associated with forest conversion in the humid tropics, especially Latin America, with related impacts on biological diversity, soil erosion, and greenhouse gas emissions. In areas with high concentrations of livestock production (such as parts of Southeast Asia), excesses of nutrients can accumulate in the soil, resulting in water pollution and greenhouse gas emissions. Extensive grazing has been associated with loss of vegetative land cover, soil compaction, and desertification. The impacts of livestock on the environment depend on site-specific and management conditions; a comprehensive discussion of impacts is beyond the scope of this article. Rather, this article presents three main issues that illustrate the scope of livestock-environment interactions in the developing world and principles that can enhance people's understanding of how to respond to environmental degradation resulting from livestock production.

Cattle and Forest Conversion in the Latin American Tropics

Cattle have been widely vilified in the popular and policy-oriented literature for their role in tropical deforestation. Although livestock indeed have been associated with deforestation and other environmental impacts in some parts of the tropics, there is a need to more closely examine what this role has been, where it has or has not been a problem, and what might be done about it.

As concern for tropical deforestation became an important international issue in the late 1980s, considerable attention was focused on the role of cattle in the deforestation process. In an article published in *The Ecologist*, James D. Nations and Daniel T. Komer described a generalized deforestation process for Central America:[8]

- logging companies enter the forest to extract valuable hardwoods;
- the roads left behind by the logging companies are used by colonists from other parts of the country who plant crops that are ill-suited to the tropical forest climate;
- land cleared by the initial colonists is acquired by individuals or companies to produce export crops, particularly beef; and
- land productivity is low and declines rapidly with soil nutrient depletion.

This process was assumed to produce few local benefits and appeared driven by the U.S. beef market, principally for the fast food industry. Additionally, this process was abetted by subsidies from commercial and international development banks seeking to help tropical countries diversify their exports.[9]

This simplified and overgeneralized story gave rise to erroneous environmental policy recommendations and political strategies.[10] Cattle were associated with deforestation principally in Central America and in the Amazon. Fresh beef from the Amazon, like nearly all of South America, could not be imported into the United States because of restrictions on receiving food from areas with cattle contaminated by foot-and-mouth disease (a highly contagious viral cattle disease that can cause economic losses). Therefore, a suite of social and economic factors more complex than the export demand for beef probably caused the rapid rate of tropical forest loss in Central America in the 1970s and 1980s. First, coarse-grained maps of deforestation in Costa Rica may have overestimated the rate of deforestation by a factor of two. Second, the Central American cattle industry endured an economic crisis in the 1980s because of sluggish export demand, higher taxes and indebtedness, and soaring costs, foreshadowing larger declines in the industry in the 1990s. In retrospect, much of the forest-to-pasture conversion in Central America that took place in the 1970s and 1980s was associated with a colonization process founded on subsidies from nature and the state.

For example, in Costa Rica, there is now general agreement that the rapid expansion of the frontier and concomitant widespread conversion of forests to pastures in Central America was driven largely by factors other than productive land use. Specifically, conversion was not the result of what Nations and Komer labeled the "hamburger connection," the theory that U.S. consumer demand for beef drove deforestation in Latin America. Although cattle markets played a role, at least equally important was a process of land speculation, supported by government policies, in which land was cleared and kept clear of trees as part of a process of claiming public or absentee-owned lands for private benefit and also as a way of defending against these actions.[11] In the Amazon, a similar process of forest-to-pasture conversion has been reported. Deforestation rates were overestimated because of coarse resolution analysis and failure to

Use of Feed Resources by Livestock in Developing Countries

Although it is less directly connected with environmental impacts of livestock production, an additional issue merits comment here. A common assumption is that livestock compete directly with humans for the same food—an assumption which is frequently invalid in developed and developing countries.[1]

Diets of all food-producing livestock include human-inedible feedstuffs. Animals convert these byproducts to human-edible foods rich in protein, energy, and micronutrients. Disposal of these byproducts in other ways would require additional resources. Diets for swine, poultry, and beef cattle in feedlots typically contain between one-third and one-half human-inedible ingredients. At least one-half of the final live weight of beef cattle is obtained from forage fed prior to the feedlot phase. In addition, less grain is fed to animals and more is produced when grain prices rise, thus reducing competition with humans for food grain supplies. Grain fed per unit of meat is about 0.3 for cattle, sheep, and goats, 1.6 for poultry, and 1.8 for swine. Ruminants return more human food per unit of human-edible feed than other livestock species because humans do not directly consume most of the ingredients in their diets.

Globally, livestock produce one unit of human food protein per 1.4 units of human edible protein fed to them. The biological value (a measure of the adequacy of protein sources relative to human dietary requirements) of animal protein is about 1.4 times greater than the value of protein from plants. Sheep, goats, and dairy (milk) cattle throughout the world produce more than one unit of human food per unit of grain consumed. Beef cattle in developing countries, where little grain is fed to them, also produce more human food than the amount of grain consumed. Evidence suggests that between one and fourteen units of milk protein is produced per unit of protein from human-edible food. As a result, shifting grain from animal use to direct consumption by humans would have relatively little effect on total available protein, but it would decrease average dietary quality.

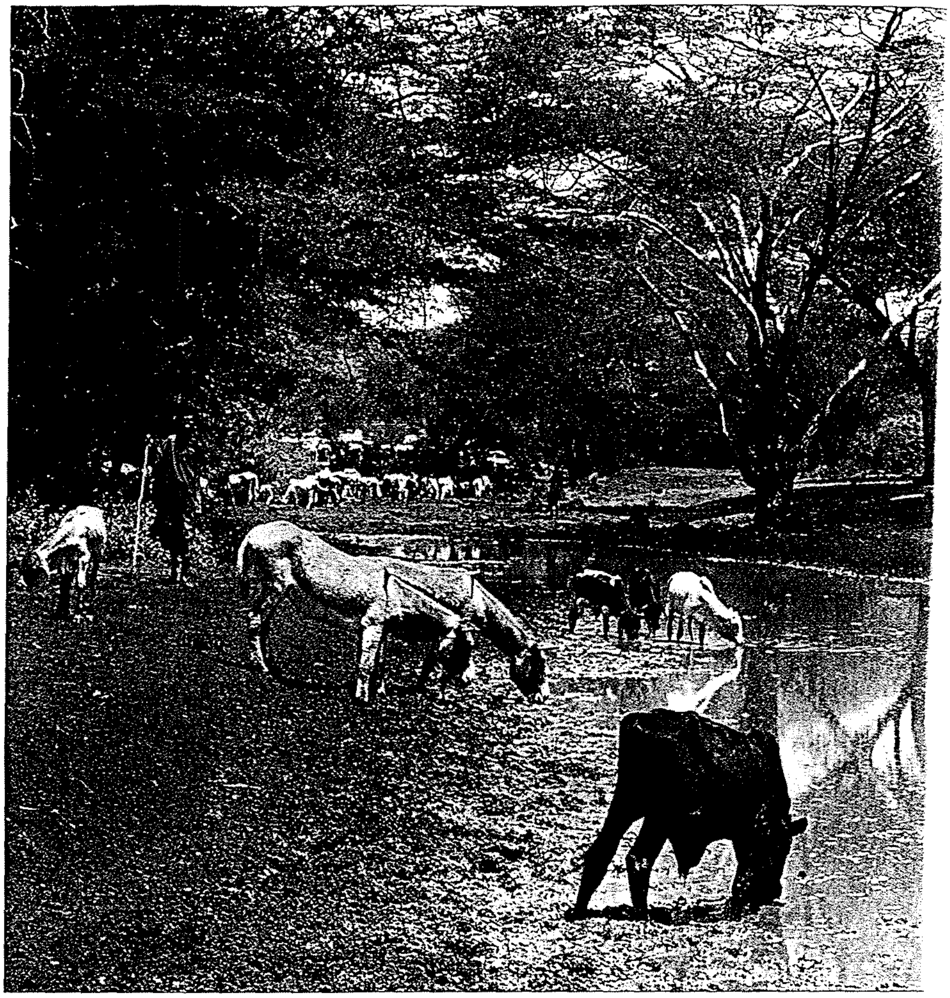
1. Council for Agricultural Science and Technology, *Animal Agriculture and Global Food Supply*, Task Force Report No. 135 (Ames, Iowa: Council for Agricultural Science and Technology, 1999).

account for forest regrowth, policy incentives that encourage cattle ranching, and planned government colonization programs.[12]

Pasture expansion in the Amazon is only loosely associated with cattle markets or population growth.[13] Rather, cattle expansion can be understood as a combined effort to capture subsidies and credits and to claim land for speculative purposes. The cattle-to-pasture expansion in Costa Rica was largely driven by the government-sanctioned land claiming process in which moral authority is gained by demonstrating "productive" use of land.[14] The result was that large landowners maintained their pastures to demonstrate use of large land areas using minimum labor investment and to discourage squatter invasion. Meanwhile, smallholder colonists (squatters) converted forests to pasture to demonstrate that their land was not being underutilized.

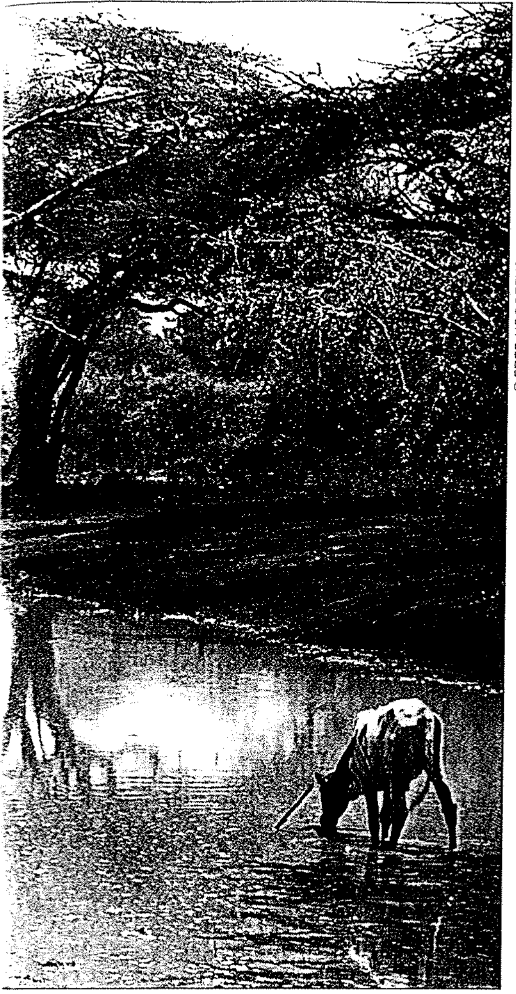
These larger and more prominent processes overshadow the fact that cattle production is an attractive economic option for small-scale landholders. Cattle in the Amazon and Costa Rica are an important component of smallholder land-use strategies because of their biological flexibility and economic features. Cattle provide a low risk, low labor farm option that have flexible harvest times and can be brought to market even from remote areas with poor roads. Livestock production is an important investment strategy, especially in highly inflationary economies. Although pastures may degrade in poor soil conditions, they can be intensified by smallholders under favorable economic conditions.[15] Alternatives to cattle production, such as nontimber forest products, conservation-based enterprises, and agroforestry have turned out to be small, niche-specific options with limited adoption. However, a combination of government incentives for forest conservation and reforestation and the perception that forests can increase land values more than pastures may stimulate forestry as the land use of choice for economic returns.[16]

Although the biological diversity of agroecosystems is generally lower than that of more "natural" ecosystems and decreases with agricultural intensification,[17] when viewed over larger spatial and temporal scales, promoting farming successes would favor the environment more than failures with continued colonization of remaining forest lands. Much of the tropical forest destruction that has taken place in the past three decades in Latin America was associated with recurring cycles of colonization—either from farm failure or consolidation of smallholder farms into large landholdings—and the subsequent colonization of other forested areas.[18] The results support arguments that livestock play an important role in successful farming systems, large and small, and should not be ignored.



Maasai and their livestock at a seasonal river in Kenya. In arid northern Kenya, wildlife avoid concentrations of people and livestock around watering points, limiting wildlife access to resources necessary for their survival.

In addition, the relationship between forest conversion and biodiversity has often been oversimplified. Remnant trees in pastures can serve as "island refuges" for a wide variety of bird species using canopy resources, such as epiphyte flowers and fruits and dead organic matter on trunks and branches.[19] The ecological dynamics between pasture trees and forest remnants are complex, with mixed implications for conservation. Managed acacia woodlots on grazing land in Chiapas, Mexico, are an important overwintering habitat for migrating birds. Study of bird diversity in different tree components of the agricultural landscape (scattered trees, shade patches, living fences, riparian vegetation, shade plantations, woodlots, and forest remnants) showed that each type of forest patch supports different avifauna. Most importantly, these forest patch types are complementary in their protection of avian diversity.[20] Although more empirical research on biodiversity in managed landscapes is needed, including pastures, these results suggest that increased integration of trees into farming systems can play a signifi-



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cant role in biodiversity conservation. Farmers already incorporate trees into their systems in many ways, and building these practices into viable strategies should be feasible.

Impacts of Livestock on Biodiversity in Sub-Saharan Africa

Ecologists usually define biological diversity in one of three ways: *genetic diversity*, or the wide variety of biological information stored within genes; *species diversity*, or the many different species of organisms in the world (from *E. coli* to elephants); and *ecosystem* or *landscape diversity*, or the range of habitats or vegetation types that cover the globe. These dimensions of biodiversity contain virtually all the natural information on the planet—information on how to live through drought (in camels, for example) or how to persist during fire (in bristlecone pine, for example). The rest of this article will focus on species and ecosystem diversity.

The impact of livestock on the environment in Africa varies strongly according to amount of rainfall. In arid and semi-arid areas (less than 20 inches of rainfall per year), grazing and browsing of livestock can result in competition with wildlife seeking food and water but also may make habitats more attractive to other species. Migratory pastoralists affect biodiversity by collecting wood and building settlements. Still, the nutrient patches left behind in old livestock corrals may enhance wildlife habitat rather than degrade it. In areas of Africa that receive moderate rainfall (20 to 60 inches), livestock populations are moderate to high, and their impacts on the environment can be extensive, through grazing and by allowing farmers to plow more land. In the rainforests of Africa (more than 60 inches of annual rainfall), unlike South America, there are currently few livestock, and the disease constraints on production are strong. As a result, impacts are low (although this may change in the future).

The savannas of East Africa support the greatest diversity of migrating wildlife on Earth. Pastoralists, their livestock, and wildlife have coexisted on these savannas for three millennia. Recently, however, wildlife populations have declined rapidly in many areas outside of national parks and reserves, but this is only partly because of livestock activities. In eastern Uganda, wildlife has almost disappeared because of the influx of firearms during changes in government and the ensuing poaching.[21] In northern Kenya, poaching has been rampant, but water development (for both livestock and people) is also a culprit. In Tanzania, the competition between wildlife and livestock is less intense because human population is low. Nonetheless, the spread of cultivation is excluding wildlife from certain areas.

High concentrations of livestock around settlements or water points can exclude wildlife from habitats and resources crucial for their survival. Severely denuded "sacrifice areas" around livestock watering points contain few plant species[22] and thus few resources to support other fauna. In arid northern Kenya, wildlife avoid concentrations of people and livestock around watering points.[23] The endangered Grevy's zebra is particularly affected. Mares and foals walk long distances between widely separated grazing areas and water sources because of competition with pastoral livestock herds.[24] Wildlife populations are also smaller around occupied settlements, presumably because of competition with settlement holdings of livestock.

Interventions to increase livestock production, such as fences for disease control, can also affect biodiversity. In Botswana, disease-free cattle are crucial to the economic well-being of the cattle industry. To protect this important economic activity, the veterinary department constructed stout fences to prevent the spread of disease. Thousands of Kalahari wildebeest and hartebeest died during the drought of the early 1980s, partially because veterinary fences blocked their migration in search of water. On the other hand, these same fences can protect wildlife from the expansion of farmlands and from poachers.

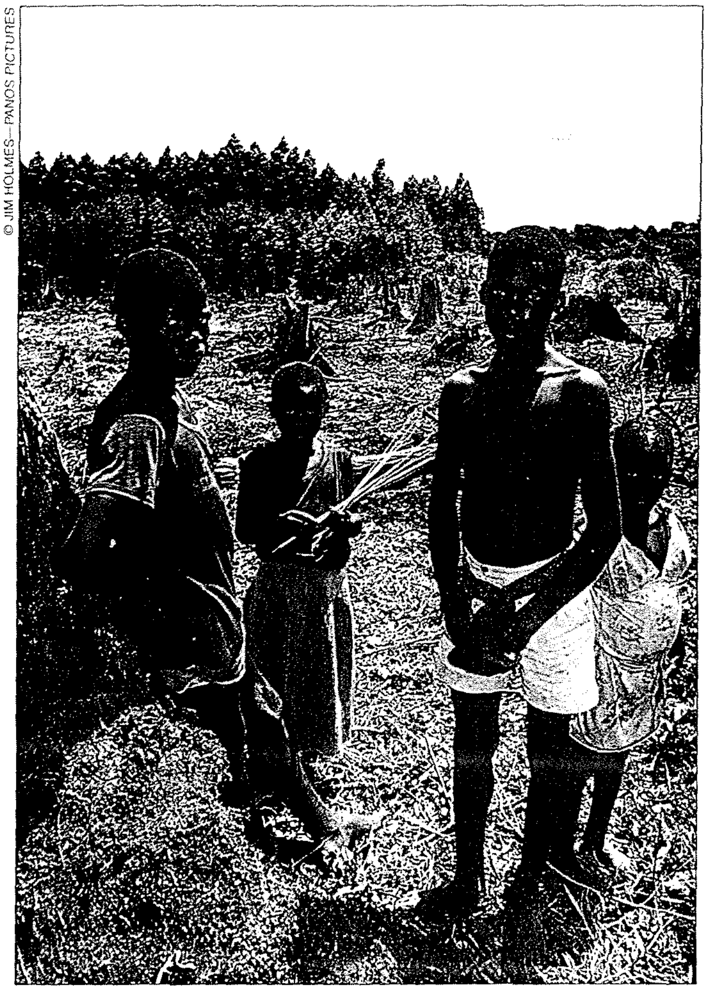
New evidence shows that, contrary to expectations, pastoral settlement practices may enrich rather than deplete rangeland biodiversity. In southern Africa, patches of nutrient-rich acacia woodland can be found in the middle of nutrient-poor savanna. Wildlife prefer these patches, and scientists speculate that they used to be Tswana cattle corrals. In East Africa, pastoralists leave behind piles of nutrients from livestock when they move seasonally to find new pastures. These nutrient hot spots are visible on the landscape for decades and often provide ideal conditions for tree regeneration.[25] In southern Kenya, wildlife and livestock prefer these old settlement sites because of the nutrient-rich grasses they foster. Settlements also open up woodland habitats so a wider range of species can use these landscapes. Old settlements probably also contribute to the diversity of plants, birds, and insects within the system.

Pastoralists and their livestock can

also affect the diversity of larger landscapes. In 1978, the Ngorongoro Conservation Authority (part of the Tanzanian government) required Maasai pastoralists to leave the Ngorongoro Crater. During decades of Maasai occupation, selective feeders that required highly nutritious forage because of their smaller body size dominated the wildlife community in the crater. Departure of the Maasai and their cattle initiated a turnover in the wildlife ecology: Unselective grazers, such as buffalo and zebra, replaced the selective feeders. One possible explanation for this shift is that livestock grazing facilitates nutrient flow to selective feeders by creating patches of plant regrowth that are more diverse and more nutritious than those originally present.[26]

In higher rainfall areas, the control of trypanosomiasis may encourage farmers to clear more forest and woodland.[27] Transmitted by the tsetse fly, trypanosomiasis occurs across 10 million square kilometers of Africa. A century ago, people avoided areas infested with tsetse. Even now, pastoralists move as the tsetse populations seasonally ebb and flow across the savanna. Once the disease is controlled, people and livestock can use an area more intensively. Most areas infested with the tsetse fly have sufficient rainfall to support agriculture, so tsetse control can encourage land clearing.

Land clearing after tsetse control would seem inevitably to cause biodiversity loss, and it can—in certain species. For example, land clearing after tsetse control universally and negatively affects large mammals.[28] However, other species are less affected. In Ethiopia and Zimbabwe, more bird and tree species are found on smallholder farms than in nearby parks and reserves.[29] Even though more tree species are found on farms, many of them are cosmopolitan, weedy species that are common elsewhere. Some species found nearby in protected areas are not found on farms, indicating an overall loss in biodiversity to the agroecosystem.



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In Uganda, children stand among burnt trees in a field being cleared for agriculture. Biomass burning of forests for crop or livestock production contributes to global warming by releasing CO_2 into the atmosphere.

The impact of livestock use on biodiversity in Africa is neither universally negative nor universally positive. In pastoral systems, where human and livestock populations are low, ecosystems are relatively intact and biodiversity is high. In more intensively used areas (near water points, settlements, and fenced areas), livestock production can have strong negative impacts on a variety of species. The most pronounced impacts probably occur with expansion of agriculture into little-used forests and woodlands. In these instances, larger or more sensitive species will be most affected, and smaller or less fragile species will persist alongside people and their livestock.

Livestock and Greenhouse Gas Emissions

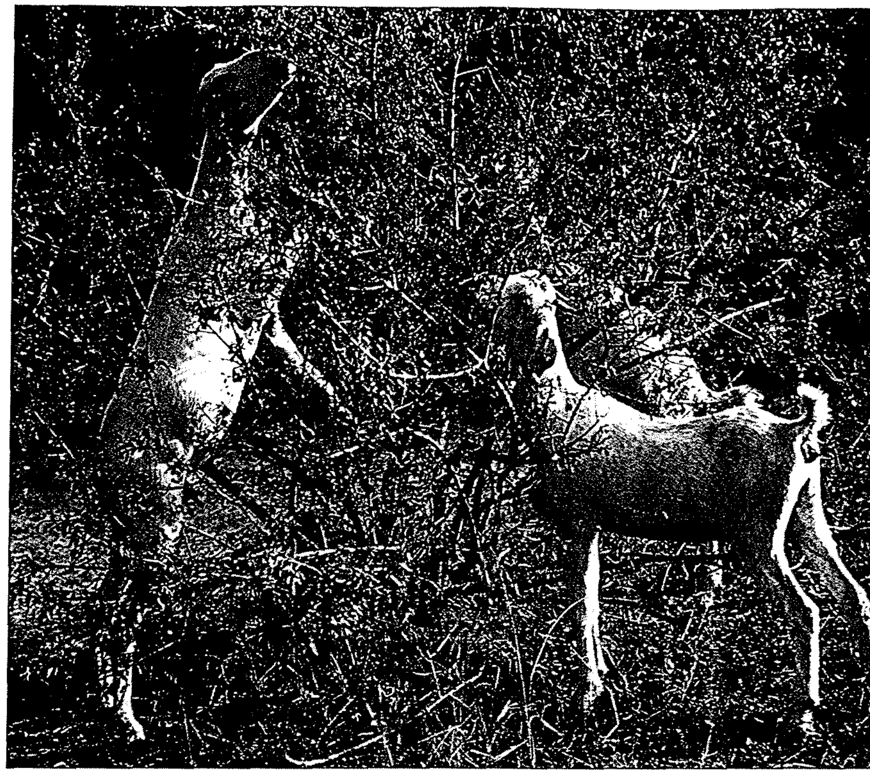
In addition to livestock's site-specific and landscape-level effects discussed earlier, livestock contribute to a problem that is global in scale: greenhouse gas emissions. The key gases of concern are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). To understand the impact of livestock on greenhouse gas emissions, it is necessary to consider effects on emissions sources and the sinks that absorb or sequester them.

Forest conversion is the main land-use change affecting the concentration of greenhouse gases in the atmosphere. Most CO_2 emissions worldwide from agriculture result from biomass burning to convert forests to crop or livestock production. Further, tropical forests serve as a sink for CO_2, so forest clearing also reduces the rate at which it is removed from the atmosphere. However, subsequent plant growth in cropland and pastures offsets this effect to a small extent. Periodic burning of savanna grasslands to maintain their productivity for extensive grazing—most common in Africa—also results in CO_2 emissions. Estimates of the contribution of all land-use changes to the net flux of CO_2 have varied from 7 to 34 percent.[30] Thus, to the extent that forest conversion and biomass burning result from animal agriculture (especially cattle) per se, livestock contribute to increasing concentrations of atmospheric CO_2. The use of fossil fuels for livestock-related manufacturing, transportation, and feed production also contribute to atmospheric concentrations, but the extent is unknown.

When considered over 100 years, CH_4 has a warming potential 20 times that of CO_2. Methane also reduces the rate at which tropospheric ozone—itself a powerful greenhouse gas—is removed from the atmosphere. The main sources of CH_4 emissions are natural wetlands and rice paddies, whereas the atmosphere and soil microbes are the major sinks. Methane from livestock production arises primarily from ruminants. Methane results from fermentation in the rumen, manure from grazing, and storage of manure under anaerobic conditions (e.g., in lagoons without contact with air). The production of CH_4 in the rumen is related to dietary quality. Forage-based diets, which have relatively low digestibility, result in greater CH_4 emissions per animal unit and per unit of milk or beef. Low-quality forage and crop residues are the principal feeds for ruminants in the developing world, so emissions per unit of product are typically higher than in the developed world. Improving diet quality offers the opportunity to improve animal productivity and to reduce CH_4 emissions per unit of food produced.

Although manure from grazing animals affects net CH_4 emissions from soil, it is insignificant compared to rumen production by animals. Methane from anaerobic storage of manure (mostly from larger, more intensive production systems involving nonruminants) contributes about 20 percent of the total emissions from livestock. Combined, these sources account for about 16 percent of global emissions, although their contributions to past increases in methane are poorly understood.[31] Forest conversion (and related biomass burning) contributes directly to emissions; it also decreases the capacity of soils to absorb CH_4.

Nitrous oxide has a warming potential more than 300 times that of CO_2. Most N_2O production from livestock in the developing world is direct emissions from manure. Animal manure contributes about 10 percent of global N_2O emissions, with more than two-thirds of this from the larger animal populations in developing countries. Other sources are the production of forage and feed grains, including the production of nitrogenous fertilizers. Pastures established on forest remnants release substantially more N_2O than forested land. Knowledge about the global N_2O budget is largely incomplete.[32]



Goats feeding on young trees in West Africa. Grazing systems typically include ruminant species—goats, sheep, and cattle, for example—that rely on native rangeland or grassland without the integration of crops or external inputs, such as feed and fertilizer.

In sum, livestock production contributes key greenhouse gas emissions. Although livestock's contribution to global emissions is uncertain—because of measurement challenges and the extent to which land-use changes are attributed to livestock—there is value in reducing emissions caused by livestock. Despite the promising technological options, this issue has received little attention from policy makers in either the developed or developing world. Carbon dioxide emissions are best addressed by policies directed at the underlying causes of land-use change, discussed earlier. Methane emissions should be the target of livestock-specific policies, given the potential for increasing productivity through reduction of dietary energy lost in methane. Strategies for CH_4 reduction that need additional evaluation in the developing world include improving forage quality, feeding starches that resist fermentation in the rumen, and use of additives that reduce rumen methane production. Improved nutrient management, particularly in crop-livestock systems, can also reduce CH_4 and N_2O emissions.

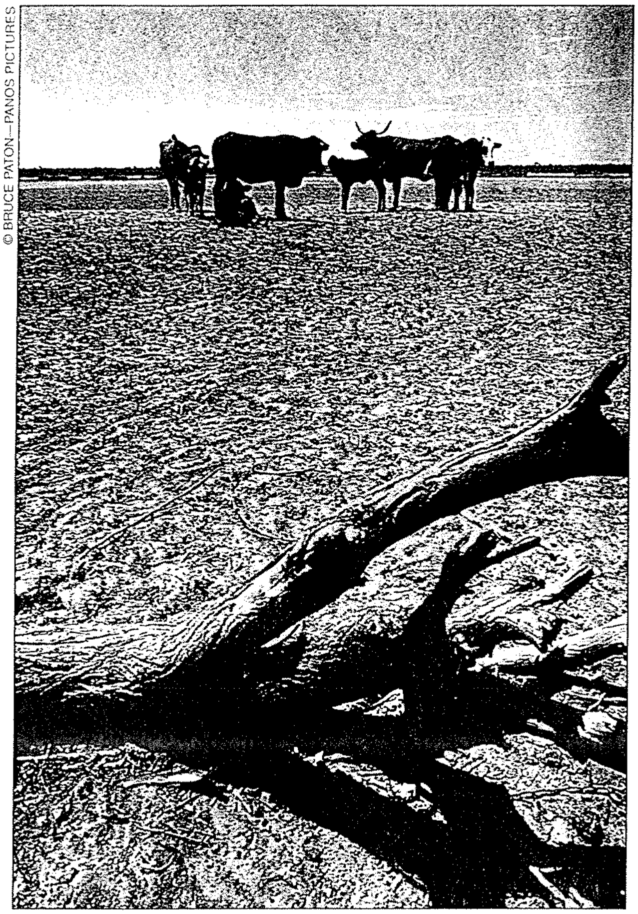
Principles for Assessing Livestock Systems in the Developing World

The foregoing discussion of the benefits and environmental costs of animal agriculture in the developing world illustrates that policy makers in the developing world face tradeoffs between livestock production and environmental outcomes.[33] Several principles assessing these tradeoffs should be followed for policy decisions to address environmental concerns.

One principle is that environmental impacts of livestock are rarely universally positive or universally negative, as noted earlier for tropical America and sub-Saharan Africa. Another example is desertification in the Sahel region, which was blamed primarily on overstocking in extensive production systems. This conclusion is being reconsidered in light of evidence that grazing systems are more resilient than once thought, even for the worst-case situations.[34] These cases suggest that policy makers and researchers need to remain open to new information on the nature and magnitude of livestock-environment interactions.

This reappraisal of the forest-to-pasture conversion process suggests that policy makers and researchers would benefit from more accurate information about cattle-environment relationships in the tropics. The most useful information for decisionmaking will

- be site specific;
- examine the environmental impacts and social factors across broad spatial and temporal scales;
- facilitate conclusions and policies based on empirical results set within this holistic framework;
- seek workable and adoptable ways to reduce undesirable environmental impacts; and
- acknowledge and, where sensible, retain the important role of livestock in food systems.



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Cattle in the Kalahari desert during a drought. The impact of livestock on the environment in Africa varies strongly according to the amount of rainfall.

As this article illustrates, livestock are usually a means to an improved end for rural citizens of the developing world. As a result, the estimation of the benefits of livestock production must include more than just the direct value of food production. Other important contributions, such as using animals for traction, transportation, and as a savings mechanism, need to be accounted for when evaluating the benefits to livestock owners.

More inclusive estimates of the benefits of livestock production can also lead to more effective decisions about agricultural development strategies. Studies that document the total environmental costs of livestock production can be useful to make informed policy choices but perhaps not so useful as those providing comparisons of costs and benefits of various management strategies designed to meet the needs of the people in the developing world. Total cost calculations often implicitly involve comparisons of environmental outcomes with livestock and without livestock.[35] Because the "without livestock" option is unlikely to be realizable except in cases such as establishment of certain protected areas, total cost estimates are of limited usefulness in formulating policy. Instead, additional information is necessary on the magnitude of improvements from existing outcomes that can be achieved using different livestock species, management practices, and technologies. Information on options that can increase the benefits and decrease the environmental costs of livestock production is particularly limited in the developing world.

Another principle arises from the observation that many assessments focusing on the direct impact of livestock on the environment exclude interactions with crop agriculture. The benefits and costs associated with these interactions must be considered to adequately evaluate the impacts of livestock on the environment. Examples include nutrient cycling from livestock to crops (a benefit) and water contamination from agricultural chemicals used in feed production (a cost). Assessment of options to mitigate the environmental damage of agriculture should examine both crop and livestock activities, not one or the other in isolation. It is important to avoid creating a false dichotomy in which livestock and crop agriculture are separate entities for which the environmental outcomes of one are assumed to be superior to the other. Evidence has shown that agricultural systems with livestock can be less damaging than cropping alone and can help restore productivity of degraded lands through nutrient recycling.[36]

It is also helpful to distinguish problems stemming from livestock production per se (e.g., from increases in the demand for foods of animal origin) and from other needs or incentives of peoples of the developing world. At a basic level, environmental problems attributed to livestock result from management—and sometimes survival—decisions made by humans. The underlying causes of environmental degradation from livestock include poverty, population growth, economic growth, incomplete understanding of agroecosystem dynamics, urbanization, social inequality, and weaknesses in governing and enforcement institutions.[37] Because these are powerful underlying factors, other forces not directly related to agriculture may overwhelm solutions targeted only to direct degradation by livestock.

Given the benefits of animal agriculture in the developing world and the subtleties associated with assessing interactions with the environment, blanket condemnation of livestock production is unwarranted. Policies and institutions that maximize the benefits (especially for low-income rural people) and minimize environmental damage are preferable. Using the foregoing principles for assessing these interactions, policy makers, researchers, and international donors must carefully examine the policies, regulations, programs, and projects for improving the contribution of livestock to human welfare and environmental outcomes.

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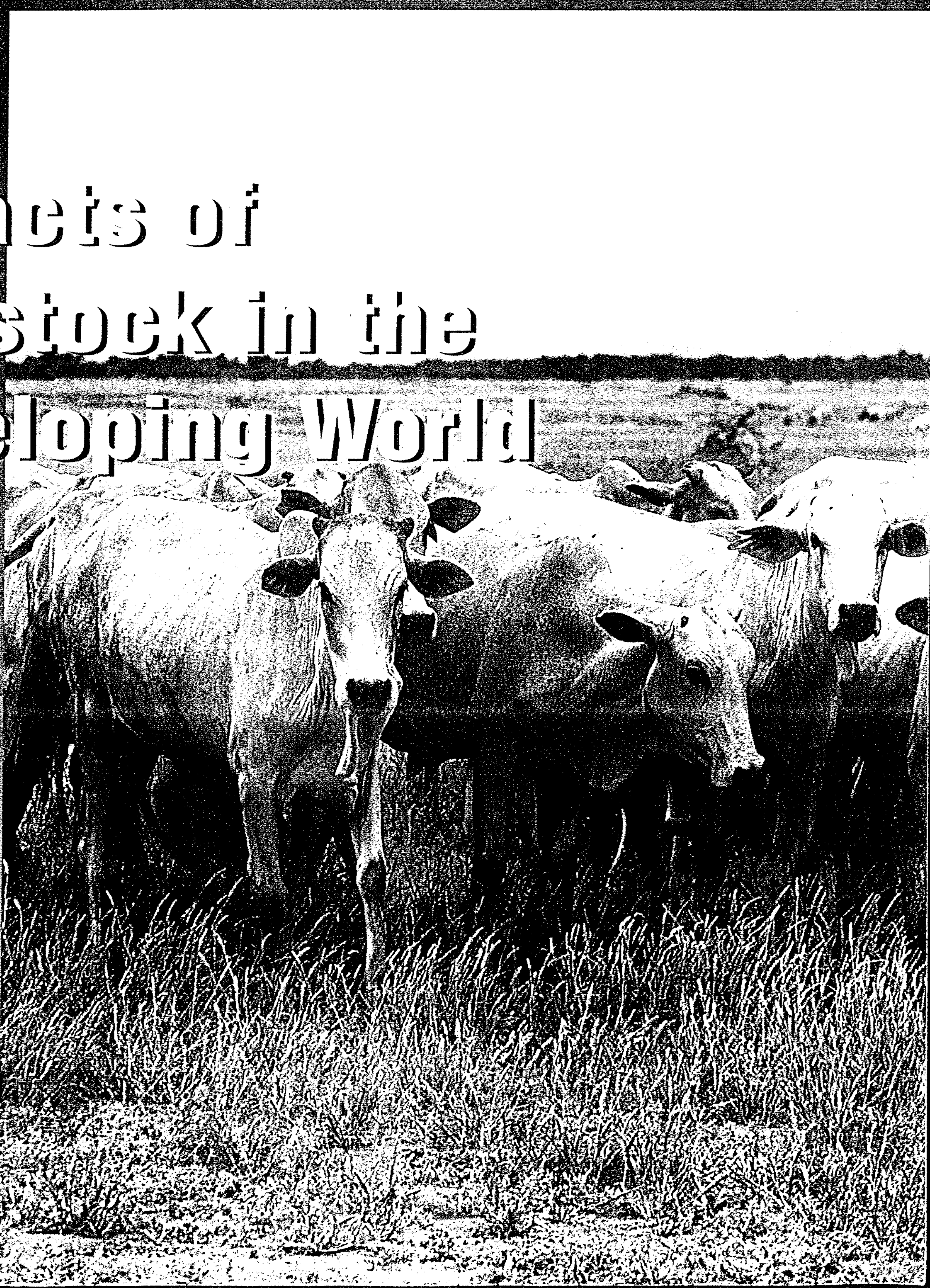

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Livestock provide substantial benefits to people in the developing world but also contribute to environmental degradation. Photograph © Crispin Hughes—Panos Pictures.